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N64 13271

CODE-1

CR-53021

Technical Report No. 32-399

The Role of Soil Science in Space Exploration

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OTS PRICE

XEROX $ 1.60 ph.

MICROFILM $ 0.80 mf.

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CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

February 16, 1963

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(NASA CR-53021; JPL-TR-32-399) OTS: $1.60 ph, $0.80 mf

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
(NASA CONTRACT NO. NAS 7-100)

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The Role of Soil Science in Space Exploration

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New frontiers in soil science are currently found in the investigation of soils in harsh, terrestrial and simulated extraterrestrial environments, the development of new methods and probes for soil characterization, and the eventual investigation, characterization, and development of extraterrestrial soil. Current aspects of space science involving soil studies are presented, including a more detailed soil study program involving the microflora of desert soil ecosystems. Basic precepts are given for preparation, investigation, and use of extraterrestrial soil.

"The soil lies on the twilight of life, a connecting link between the living and the non-living, between material animated by vital forces and material subjected to physical forces.–[it] is itself both the product and the indispensible support of organic life on the earth (Ref. 1)."

AUTHOR

I. INTRODUCTION

The exploration of outer space should be of vital importance to soil scientists, although at the present time the science as a whole has not been recognized in the space program. This neglect is partly due to a lack of interest by soil scientists, or else a lack of their knowledge of certain facets of space projects which involve problems and goals not yet realized in the study of the soil. In this respect it should be noted that the search for extraterrestrial life involves an investigation of the soil, particularly for evidence of microbial life (Ref. 2 & 3). Unique methods and procedures have been devised for this purpose for sampling, processing, and observing soil by automation (Ref. 4 & 5). For those involved in soil organic matter analyses, new methods and techniques have been evolved utilizing a compact gas chromatograph applicable to chemical analyses of soils and soil-like materials (Ref. 6). A new field is also developing in the sterilization of space probe systems, and soil sterilization in an intimate part of the program (Ref. 7). It is essential that no organic contamination be transplanted from the earth into an extraterrestrial environment, and that no contamination be brought back to earth via a return vehicle, whether automated or manned. With regard to this problem, harsh environmental research has also been conducted to determine the response of soil microorganisms in ultra-high vacuum (Ref. 8). Experiments of this nature would indicate the tolerance and survival rate of organisms subjected to simulated deep space conditions. There are also programs for detecting cultured soil microorganisms (Ref. 9) and minute amounts of substances within the soil which will provide either direct or indirect evidence of living organisms (Ref. 10 & 11).

Early tolerance and survival research (Ref. 12)[1] now consist of simulated, "Martian-type" experiments utilizing terrestrial soils (Ref. 13 & 14) including those from California desert areas (Ref. 15). Even those who investigate carbonaceous chondrites for extraterrestrial biological materials must be concerned with contaminating soils and organisms (Ref. 16, 17, 18, 19 & 20). Furthermore, there is the need for probes which will give us information about a planetary environment (Ref. 21), and in this regard it can be emphasized that these probes should include a small, compact package for obtaining concise information about the soil and its surroundings—that volume of the environment known as the soil ecosystem (Ref. 22). Such probes would be of value either preceding or following manned space flight and landings. Current programs do have probes of some interest to soil scientists, but mainly for soil engineers. On the lunar surface, for example, geophysical experiments may include measurements for bearing strength, shear, compression, thermal conductivity, and surface temperature (Ref. 23).

What may be of more importance or interest to soil scientists, as well as others, is the anticipated return of lunar and planetary surface or subsurface samples. Regardless of the changes that may occur during transit of the return sample, valuable information could be obtained by the soil scientist on planetary evolution and environment, e.g., climate, soil genesis and morphology, and an indication of certain physical, chemical, and biological properties of the soil such as moisture holding capacity, particle-size distribution, abundance of essential and available nutrients, and possibly the abundance and nature of any organic matter and indigenous organisms. It is to be realized, of course, that too much emphasis should not be placed on the analysis and interpretation of results obtained from *one unit* of return sample. It is a well recognized fact on this planet that many soil samples must be obtained in order to have representation of a volume of soil or a given area. Soil is quite heterogeneous and even one soil ecosystem may have little in common with properties of a similar ecosystem adjacent to it. However, for a planet with less variance in the range of soil-forming factors, i.e., organisms (including soil management by humans), climate, parent material, topography, and time, this may not be too important. It could well be that all of the soil-forming factors are not operative in an extraterrestrial environment. Vegetation, climate, and parent material, considered to be primary soil-forming factors on this planet, may not be the most important factors in an extraterrestrial environment, and the factors to be emphasized in such a case may be time and topography with primary emphasis given to the endodynamorphic factor—parent material. In the latter instance, a single random sample may be quite representative of a large area of extraterrestrial material.

Much of the neglect of soil science in current space programs is also due to the relative scientific anonomity of soil scientists to space scientists. Therefore, many space scientists do not know the functions of soil scientists, they have little knowledge of the value of the scientific study of soils, and they are not aware of the contributions that can be made by soil scientists to space research and exploration. Many space scientists do not realize the implications and complexities involved in the study of soils, and unfortunately, most do not know what "soil" (or "soils") means in soil science (Ref. 24). To many it is considered as so much dirt or rock-like debris, and it is not realized that the soil of our planet has evolved, is necessary for life, is basically responsible for the cyclic transformations of carbon and nitrogen, and that finally, it is both living *and* a physico-biochemical system in dynamic equilibrium with its surrounding environment. Any unit of soil, its dependent organisms and adjacent surface atmosphere (meteorological microclimate) is a complex, dynamic ecosystem having physical, chemical, and biological properties and subsequent inter- and intra-reactions within its own ecosystem, and between surrounding systems of soil, organisms, atmosphere, and parent material. Despite the recognition which can be given these basic soil characteristics, it may now be necessary for the soil scientist, whether pedologist or edaphologist, to compromise on what does or does not constitute "soil." Lunar surface material is considered to be "soil" by some scientists and engineers, and soil scientists should not neglect the study of crust materials from Mars or Venus if it lacks a profile of distinctive horizons

[1] Charles B. Lipman's early work provided information on microbiological research of arid soils. Subsequent research included experiments of an exobiological nature. These were investigations for living organisms and organic products in bizarre habitats such as old adobe, coal, ancient rocks, and even stony meteorites. The latter are now of considerable interest as evidenced by the research of microbiologists, geochemists, biochemists, astronomers, and others. His later work was devoted to tolerance and survival experiments on seeds, spores, and microorganisms in liquid air and at temperatures near absolute zero where respiration could no longer be detected. He was also interested in longevity of organisms and was the first to determine that dried algal herbarium specimens could be revived after decades of desiccation.

or shows no evidence of an active biological transformation. It may well be that the soil of another planet is quite juvenile, yet has evolved over a considerable time period, has been produced primarily by physical weathering through extreme temperature fluctuations, has no distinguishable profile, practically no depth, no available moisture, a unique soil atmosphere of methane, nitrogen, or ammonia, and no extant biota. Such a soil would indeed be unique, but even some terrestrial soils are formed under thermogenic (or cryogenic) conditions and a low biotic influence (Ref. 25). Without a doubt the study of extraterrestrial soil will provide new challenges to soil scientists, and it is well worth considering that even if there is no life within or dependent upon extraterrestrial soil at this time, soil scientists and agronomists will have the human and animal lives of an extraterrestrial colony of tomorrow dependent upon them for existence in an otherwise unproductive environment.

II. RUSSIAN EXOBIOLOGY IN RELATION TO SOIL SCIENCE

As a complication in space research and exploration it must be remembered that ideological concepts of Western and Soviet societies differ and will add impetus to exploration by two groups who are in apposition, rather than engaged in cooperative projects. Just as the Soviets have their own programs for the development of marginal lands, they have their own programs for space research and exploration. In preparation for space exploration these programs include the response of microorganisms to harsh environments (Ref. 26 & 27), and the determination and characterization of microorganisms in extraterrestrial soils (Ref. 28). In the field of microbiology, for example, they have noted that we have an advantage with excellent laboratory equipment, labor-saving automation, and high quality reagents, etc., but it has also been noted that we have performed a comparatively small amount of work in the fields of soil microbiology, systematics, distribution of microbes, cytology, geomicrobiology, and several others (Ref. 29). It should be obvious that such criticism also points out our need for more basic research in these same fields before we can adequately investigate the possible microbial life of another planet. It should also be remembered that the scientific study of the soil began in Russia and that basic research in soils, as well as that of a practical nature, has continued unabated (Ref. 30). Some of their published work shows applications useful to the study of extraterrestrial soil, e.g., the detection of living microorganisms by fluorescence techniques (Ref. 31), and the development of a soil oxidation-reduction potential electrode (Ref. 32). They consider that they are the world leaders in soil science and ahead of foreign achievements (Ref. 33). No doubt their own goals in space will include extraterrestrial colonization and accompanying investigations of the soil for structural design purposes, crop production, and modification of the natural surface environment through development and control of soil ecosystems.

III. PREPARATION FOR EXPLORATION OF EXTRATERRESTRIAL SOILS

Basic research in soils has suffered in that it has been tied too closely to practicalities (Ref. 34). It has suffered not only for economic reasons, but from a lack of stimulation when definable returns could not be envisioned. Therefore, we have very little background information for *in situ*, noncultivated and/or unproductive soils, particularly in harsh desert environments such as the high Himalayas (Ref. 35), the Sahara (Ref. 36), and the Antarctic (Ref. 37). In the United States this is exemplified by the almost total lack of soil surveys in western arid regions (Fig. 1) which constitutes more than four-tenths of our country, exclusive of Alaska (Ref. 38). In the harshest of these desert areas climate can be considered of primary importance, and biotic factors of secondary importance in soil formation.

The cloud cover is frequently high, thin, or negligible, radiation is intense, temperatures have a relatively high mean, the evapotranspiration rate is high, humidity is low, and rainfall scantly distributed and infrequent with rapid runoff occurring during an occasional monsoon-type storm. Soil development is accordingly quite poor, the depth is oftentimes shallow, well-defined structure is lacking, there is little effect of leaching, salinity may be high, and the amount of organic matter exceedingly low with a relatively small number of microorganisms and xerophytic plants except in certain more favorable microenvironments. It is for desert soil ecosystems such as these that we must have more detailed information for logical design, development, and instrumentation of space probes for extraterrestrial soils and their indigenous microflora. However, it should not be misconstrued that our deserts closely approximate an extraterrestrial environment. Except for our own planet, we do not expect to find as favorable a planetary environment anywhere else in our solar system (Ref. 39). We must therefore examine the harshest environments on our own planet in preparation for investigation of the harshest types of conditions in an extraterrestrial environment, and we must also be able to interpret any relayed data or return sample from an extraterrestrial environment in the same terms.

Besides obtaining basic background information on the properties and characteristics of desert soil ecosystems, we vitally need to know and be able to measure the environmental conditions of an extraterrestrial ecosystem which are limiting to the survival and maintenance of terrestrial life. This would include not only an analysis of the soil, but also an analysis of the microclimate of the atmosphere above the surface of the soil which is representative of the living space of macroorganisms (Ref. 40). As indicated previously, the soil and its overlying atmosphere are in dynamic equilibrium with each other. It is the soil and its dependent biota which renew the atmosphere of our planet (and that would probably substantially renew the atmosphere of another planetary environment, even if composed primarily of hydrogen, nitrogen, methane, or ammonia). Therefore, in an extraterrestrial environment we should be able to determine accurately, and within a reasonable time period, basic physical, chemical, and possible biological characteristics of the soil which are most relevant to biotic and climatic processes. These could include measurement of the following soil properties (Ref. 41): (1) moisture—bound and available, (2) surface and subsurface temperature—maximum, minimum, and diurnal, (3) quantity and quality of radiation received at the soil surface, (4) gas exchange and composition—particularly carbon dioxide and oxygen, but also any other major gaseous constituent, (5) essential elements and soluble salts—particularly the available biogenic salts of carbon, nitrogen, phosphorus, and sulfur, (6) organic matter—including the nature, distribution, and composition of possible indigenous organisms, (7) soil pH, (8) oxidation-reduction potential (Eh), (9) porosity and air pressure, (10) texture, (11) structure, (12) bulk density, and (13) color (Munsell notation). All of these properties include or indicate limiting factors for life to a greater or lesser extent, and determine the kinds of dependent and interacting biota in a particular soil ecosystem.

Current methods and techniques used in basic soils investigations, particularly in the field, are generally inadequate for determining soil properties *in situ*. Moisture, for example, has long been a special field of investigation (Ref. 42), but a review of methods shows that no one instrument or probe has yet been devised which can satisfactorily measure all conditions of moisture in different soils (Ref. 43). Soil texture can only rapidly be estimated in the field by "feel" by experienced personnel. Only "Quick Tests," requiring human manipulations and judgments, can currently give a rough estimate of the various essential elements and their availability in field soils, although electrodes have been prepared for some specifications (Ref. 44 & 45). Soil reaction and oxidation-reduction potential measurements still require extensive investigations in the field. In this regard, pH and Eh probes are not adequate for rough field work; there are

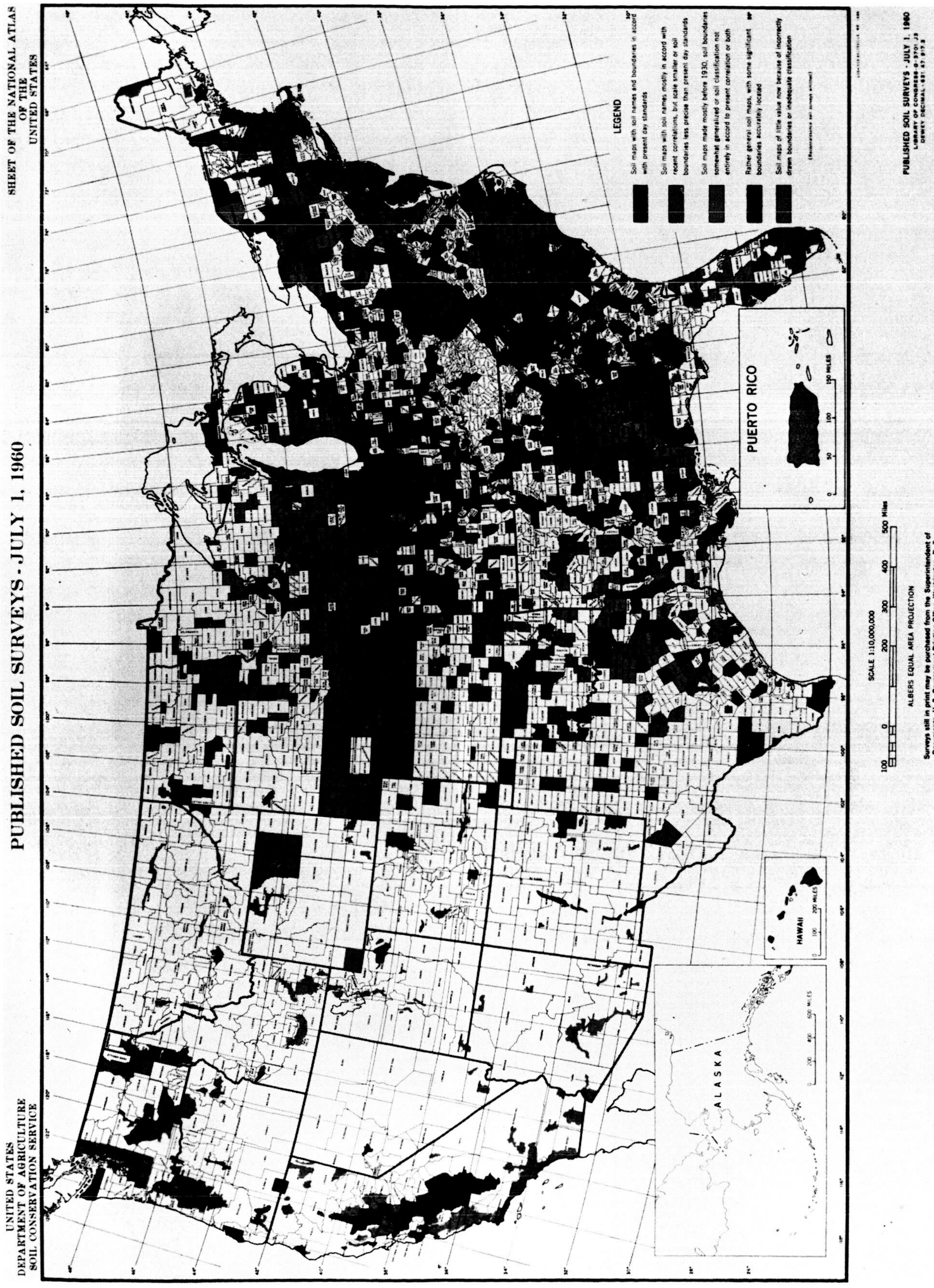

Fig. 1. Published soil surveys. White areas indicate no published surveys. Information is needed in these arid and semi-arid areas for soil ecosystems and microbial ecologies

no standard methods for the determination of Eh in soils (Ref. 46), and very little reliable background information is available for the evaluation and interpretation of results. This is also true for many other soil tests (Ref. 34). Another soil property, density, now can be determined in the field by the gamma-ray probe, but it is still too much of an empirical measurement. And, only recently have electrodes been developed which can be used for measuring respiratory gases in the field.[2] Much research is needed for testing and evaluation of these latter probes in various soil ecosystems. A small probe for soil organic matter, whether the materials are living or otherwise, has never been developed due to too many complexities of exactly what to detect and how to measure it. A probe for the determination of organic matter should be high on the priority list for its usefulness not only in space research for extraterrestrial soils, but for terrestrial soils as well since it would have enormous research value and practical usefulness in soil science and agronomy.

In conjunction with the development of soil probes must be considered the problem of probe insertion and contact with the soil matrix. Problems of this nature have plagued soil scientists since the science began. No probe can detect and measure soil properties with any degree of accuracy unless it is in intimate, or simulated, contact with the soil. In this respect, much research is still needed on current methods for probe insertion, and the development and testing of new, rapid, compact, light-weight core, drill, and insertion devices. Even more unique methods, e.g., high frequency vibrations (Ref. 47), should be of value, although one of the main objections, as for other methods, would be the disruption (thixotropy) of soil structure for probe insertion.

As a further objective, it is necessary that we have more information and understanding of the complex inter- and intra- relationships of soil ecosystems as they pertain to the indigenous microorganisms. In this field of research certain basic difficulties must also be overcome. It has been well established that selective media and techniques can be effectively used for detecting and culturing certain microorganisms, but it is a great disadvantage when dealing with unknown entities or in undertaking a broad, qualitative study (Ref. 48). At the present time, only a small portion of a population or community of soil microorganisms can be obtained *in vitro* from a soil system. These difficulties are due to (1) inability of organisms to gain a foothold on a selective synthetic medium, (2) inability of organisms to complete their life cycle on a given synthetic medium, (3) inability of organisms to survive competition and antagonisms between contaminants or associative organisms, and (4) inability of indigenous microbiota to adapt to a change in environmental conditions, whether caused by sudden exogenous changes in the physical environment, or as a result of an endogenous inhibitory environment created by the activities of the microorganisms themselves, e.g., in production and subsequent accumulation of toxic metabolic waste products in the microenvironment.

In regard to the study of soil microbial ecologies, there is also the major problem of which general morphological and physiological groups of microorganisms should be selected for study, especially in anticipation of what might be encountered in an extraterrestrial environment. In this respect, the groups to be considered are the immense numbers of structurally less complex soil microflora (as opposed to the more complex microfauna) consisting of bacteria, actinomycetes, fungi, myxomycetes, algae, lichens, and viruses. The general physiological groups considered for study would likewise be immense, but based primarily on aerobic and anaerobic soil systems, with possible emphasis given to photosynthetic and chemosynthetic organisms and anaerobic types of respiration since algae and chemosynthetic bacteria are oftentimes considered as the first organisms on the earth (Ref. 49). More specific biological problems would therefore include problems of microbial ecology with the above morphological and physiological groups of soil microflora in natural and induced environments (including simulated extraterrestrial environments) with all of its accompanying complexities. This study could be subdivided as follows (Ref. 41): (1) development of sampling, isolation, and culturing methods and techniques, (2) determination of organisms present, their associations, enumeration, occurrence, distribution, and form, (3) metabolic and physiological characteristics including microbial modification of the environment, (4) response and adaptation to a change in environment, (5) determination and measurement of the environmental parameters which cause death, or limit survival, metabolism, growth, or reproduction, (6) differential and comparative studies with microflora of similar taxa when introduced into different soils and correspondingly different ecosystems, and (7) adaptivity, survival, activity, growth, and reproduction of nondesert microflora when inocu-

[2] Beckman Instruments, Inc. Scientific and Process Instruments Division, Fullerton, California.

lated into a desert or other type of harsh environment.

Not all of the above studies can be investigated in detail any more than all of the induced and natural microbial ecologies in soils can be studied. Due to the immensity of the task outlined above, restrictions must be imposed whereby only certain of the soil factors, microbial groups, and ecologies can be considered, and in the main, these could be factors in a soil ecosystem of most importance to the survival, activities, growth, reproduction, and distribution of microbial (and non-vascular plant) populations and communities in desert soils. These areas of investigation would therefore include those regions where available moisture is very limited, temperatures are extreme, radiation is high, macro or vascular vegetation is scarce or absent, and soil development is poor (Ref. 50).

An investigation of North American deserts will give some understanding of other similar and more distant arid regions of this planet since these deserts have their counterparts in deserts of other continents (Ref. 51). For example, the Great Basin Desert has its closest parallel in the western interior of Asia. Areas of the Mohave Desert climatically approximate the Plateau of Iran and the northwestern part of the Algerian Sahara. The Colorado portion of the greater Sonoran Desert has in its driest areas conditions approaching that of the central Sahara Desert. In cooler North American regions arid parts of Wyoming and Montana resemble the Gobi Desert. Also of value are areas at high elevations which can be included in desert studies. In this respect the White Mountains of California, which are within the Great Basin Desert, are relatively arid and present opportunities for high altitude research at elevations of 10,150 to 14,245 feet (Ref. 52 & 53).

IV. DESERT MICROFLORA ECOLOGY

Present soil studies have been confined to the State of California in the Colorado, Mohave, and Great Basin deserts, and the White Mountains (Fig. 2). Measurements were made *in situ* for moisture, temperature, pH, Eh, Munsell notation, reflectivity, hardness, density, infiltration rate, and electrical conductivity. Soil oxygen and humidity were measured in the mountains. Light intensity, barometric pressure, wind velocity, air temperature and humidity were also measured at the 9 sites so far investigated. Forty-six soil samples were collected from the surface to depths of 4 feet, and precautions taken to exclude contamination of the samples. Soils were taken to the laboratory for further analyses, e.g., mechanical analysis, organic carbon and nitrogen, and numbers and kinds of microflora. Some field measurements were repeated in the laboratory. In general, it was found that field values may or may not correspond with values obtained on the dislodged and processed sample analyzed in the laboratory, and values obtained for virgin soils differ from those known for cultivated soils in a number of respects.

While only a very few soils have been examined, some preliminary remarks can be made. In the various collection sites it was noted that the structure of desertic soils is very poor, so much so that in sandy areas, where there is cohesionless soil, a wide pit must be made to obtain uncontaminated soil from various depths (Fig. 3). Sands and loams are common soils in well-drained, relatively unweathered desert areas, although clay is present (Ref.

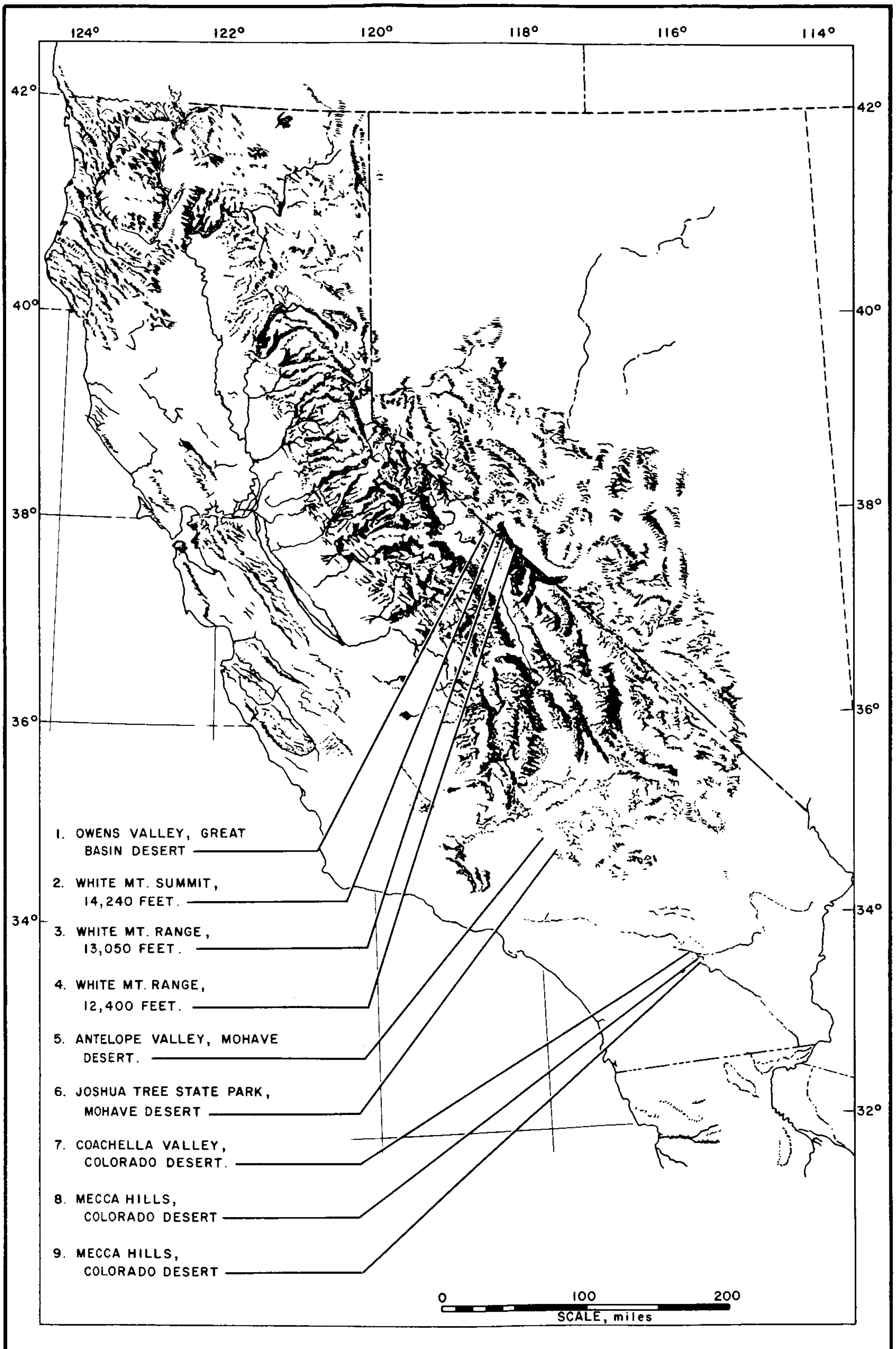

Fig. 2. Soil sites investigated for the program on desert microflora ecology

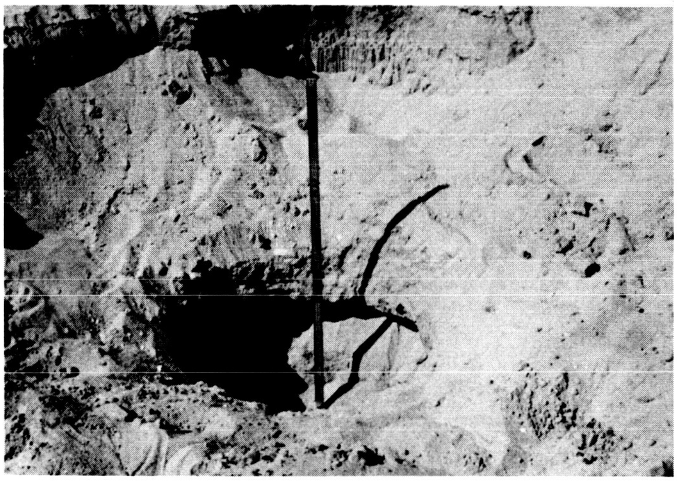

Fig. 3. Soil pit in Coachella Valley, Colorado Desert. The soil is an ancient beach sand containing sea shells. A hardpan layer is at the 2-foot level.

25). Clays are mainly derived by leaching processes (Ref. 54). Horizons of duripan or caliche layers are present due to the lack of moisture, lack of leaching, and high evaporation (Fig. 3). Salt crusts can also occur (Fig. 4). Other desert surface crusts, regardless of the kind of soil, can be found which consist of microbial organic matter, primarily of filamentous blue-green algae and associated fungi which bind the soil into a thin surface layer that impedes erosion, but also prevents water penetration during downpours. Such crusts are important

Fig. 4. Salt crusts in clay soil of Mecca Hills, Colorado Desert. Other desert soil crusts are important microecological habitats of microorganisms

microecological habitats that are higher in organic carbon and nitrogen and living microorganisms than the surrounding soil. The organic carbon in desertic soils can be as low as a few hundredths of a percent, and nitrogen accordingly low, with organic matter values corresponding to those found in igneous rocks (Ref. 34) or limestones and shales (Ref. 55). C:N values are usually narrow, sometimes as low as 3:1, and indicative of the general microbial nature and highly decomposed state of organic matter in desertic soils. The total organic matter and number of organisms, especially the algae, are usually more abundant at the soil surface, and decrease rapidly with depth. However, exceptions can be found, and these can be correlated to some extent with abrupt changes in the soil profile, with sharp differences found in structure, texture, density, porosity, moisture content, pH, Eh, color, salt content, and numbers of organisms. None of the soils so far examined have contained much less than 10^4 organisms per gram of dry soil.

As based on other measurements, the following general remarks can be made: (1) pH is usually neutral or above, (2) Eh values are commonly between +400 to +500 mv. (corrected), show more variability and are frequently lower at the soil surface than in the rest of the profile, (3) temperature fluctuations are most pronounced in the surface 6 inches; the soil surface temperature can be 50°F higher than 3 feet above the surface, (4) reflectivity values are relatively high due to the lack of moisture (and vegetation) and are commonly about half the value expected at the field capacity, (5) moisture may be as low as 0.2% in a sand or 2% in a clay (oven-dry soil), (6) bulk density, porosity, and compressive strength are quite variable, but can approach characteristics of consolidated rock in hardpan or caliche layers, and (7) soil oxygen and humidity have diurnal variations.

Three sites were investigated in the White Mountains at elevations of 12,400, 13,050, and 14,240 feet. Although the summit was covered by rough boulders and loose rocks (Fig. 5), soil was evident in a few, small, open patches and at least to a depth of one foot beneath the rocks (Fig. 6). The soil was loessial—primarily of wind-blown dust and debris, and except for an occasional small vascular plant (*Polemonium chartaceum* Mason), it was largely devoid of macro vegetation and contained microorganisms subjected to alternate freezing and thawing even during summer. Colorful, crustaceous lichens were conspicuous on the loose rocks, and algal and lichen soil crusts, typical of those found in lower, hot desert areas

Fig. 5. Soil investigation summit of White Mt., Calif. (elev. 14,240 feet). Patches of soil occurred between and beneath rocks

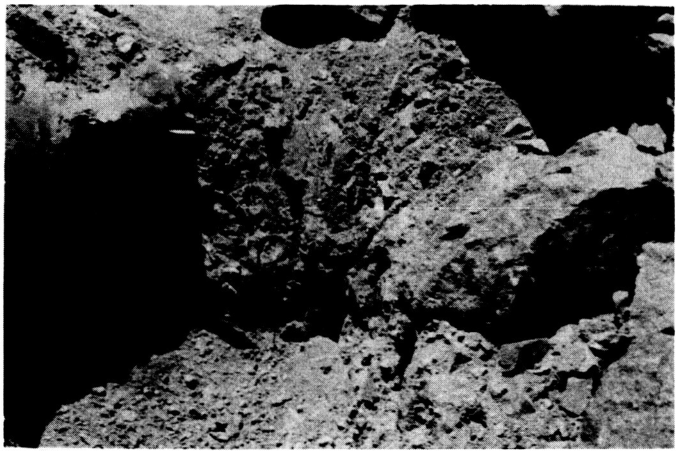

Fig. 6. Soil profile summit of White Mt., Calif. Cold, damp, loessial soil contained numbers of aerobic and anaerobic microorganisms

(Ref. 56) were also observed. These crusts contained hardy algae such as active oscillatoroid *Microcoleus vaginatus* (Vauch.) Gom., and lichenized, nitrogen-fixing *Nostoc muscorum* Ag. Both of these algae are prominent the world over in a wide variety of ecological habitats (Ref. 57). Soil actinomycetes, bacilli, and fungi were also found, and their numbers would compare favorably with their abundance and distribution in virgin desertic soils.

Additional tests will be made and correlations established. Only a few sites have been investigated and a comparatively small number of samples analyzed. But, for the purpose of investigating soil ecosystems, and particularly microbial ecology, it is of primary importance that each site be investigated thoroughly for pertinent limiting soil, climatic, and biotic factors. It is likewise important that probes and instruments be applicable to a wide variety of conditions. Unfortunately, too much of the equipment is suitable only for laboratory conditions, for cultivated soils, or for those with good profiles, and does not meet the rigorous extremes required by hot, dry deserts, or high, cold, windy mountains. Methods are also much in need of improvement and require extensive modification when used for relatively unweathered materials.

V. CONCLUSIONS

It is essential that a sound plan be developed in soil science in preparation for space exploration, and for the study, use, and/or development of extraterrestrial soils. The main considerations for investigation of harsh terrestrial environments and extraterrestrial soils can be given as follows:

A. Terrestrial Soils

1. Determination of the most pertinent properties of soil ecosystems which are limiting factors for life, especially in desert environments.
2. Measurement of predetermined physical, chemical, and biological soil properties and establishment of minimum, (optimum), and maximum values.
3. Development of a light-weight, low-power, easily-sterilized, compact package of soil probes for simple, rapid, sensitive, reliable, and accurate measurement of soil surface and subsurface properties including (1) moisture, (2) temperature (and thermal conductivity, (3) soil atmosphere (especially CO_2 and O_2), (4) soil pH, (5) Eh, (6) density, (7) porosity, (8) texture, (9) structure, (10) color, (11) reflectivity (12) salts (and minerals), and (13) organic matter, including living organisms.
4. Rational experimentation on microorganisms and nonvascular plants in soil ecosystems subjected to simulated harsh environments, and the subsequent determination of response and adaptation of indigenous or inoculated organisms and corresponding soil activity.

B. Extraterrestrial Soils

1. Determination and measurement of the pertinent physical, chemical, and biological properties of the soil ecosystem including (1) plant cover (if present), (2) atmospheric microclimate above the soil surface, and (3) soil properties, whether on a dislodged return sample or *in situ* by automation or by man.
2. Characterization of the nature, distribution, abundance, and activities of any indigenous soil microorganisms.
3. Interpretation of the nature of the soil in relation to climate, possible vegetation, soil morphogenesis, fertility, conservation, management, etc.
4. Development of soil and crops for (1) food production, and (2) necessary modification of the extraterrestrial environment for human and animal habitation and colonization.
5. Formulation of foundations and concepts of extraterrestrial soil science into a sound philosophy which is both basic and applied—one that will both add to the knowledge of our universe and provide us with practical end results.

REFERENCES

1. Marbut, C. F., Introduction, p. XV. J. S. Joffe, *Pedology,* Pedology Publishers, New Brunswick, 1949.
2. Hobby, G., "Extraterrestrial Life," *Encyclopedia of Science and Technology,* McGraw-Hill Book Co., Inc., New York, In press.
3. Horowitz, N. H., "Biology in Space," *Fed. Proc. 21*(4/1), pp. 687-691, 1962.
4. Soffen, G. A., Implication of Morphology in the Investigation of Extra-Terrestrial Life, *Ecology,* In press.
5. *Microscope System for Mars Study Program,* Contract No. JPL 950123, The General Mills Electronics Group, Minneapolis, Minn., Apr. 30, 1962.
6. Oyama, V. I., S. P. Vango and E. M. Wilson, *Applications of Gas Chromatography to the Analyses of Organics, Water, and Adsorbed Gases in the Lunar Crust;* TR 32-107, Jet Propulsion Laboratory, Pasadena, 1961.
7. *Sterilization of Space Probe Components,* NASA Research Contract NASr-31, Supplement No. 2, Wilmot Castle Co., Rochester, N. Y., June 8, 1962.
8. Morelli, F. A., F. P. Fehlner, and C. H. Stembridge, "Effect of Ultra-High Vacuum on *Bacillus subtilis* Var. Niger," *Nature,* Vol. 196, pp. 106-107, 1962.
9. Vishniac, W., Extraterrestrial Microbiology," Aerospace Medicine, Vol. 31, pp. 678-680, 1960.
10. Levin, G. V., A. H. Heim, J. R. Clendenning, and M. Thompson, "Gulliver - A Quest for Life on Mars," *Science,* Vol. 138, pp. 114-121, 1962.
11. Lederberg, J., "Exobiology: Experimental Approaches to Life Beyond the Earth," L. V. Berkner and H. Odishaw, eds. *Science in Space,* pp. 407-425. McGraw-Hill Book Co., New York, 1961.
12. Lipman, C. B., "Normal Viability of Seeds and Bacterial Spores After Exposure to Temperatures Near Absolute Zero," *Plant Physiology,* Vol. 11, pp. 201-205, 1936.
13. Kooistra, J. A., R. B. Mitchell, and H. Strughold, "The Behavior of Microorganisms Under Simulated Martian Environmental Conditions," *Publications of the Astronomical Society of the Pacific,* Vol. 70, pp. 64-69, 1957.
14. Davis, I., and J. D. Fulton, "Microbiologic Studies on Ecologic Considerations of the Martian Environment," *Aeromedecial Revue,* 2-60, 10 pp., 1959.
15. Hagen, C. A., and E. J. Hawrylewicz, "Life in Extraterrestrial Environments," ARF 3194-7, *Quarterly Status Report,* Contract No. NASr-22, Armour Research Foundation of Illinois Institute of Technology, Chicago, Ill., August 15 to November 15, 1962.
16. Briggs, M. H., "Properties of the Organic Microstructure of Some Carbonaceous Chondrites," *Nature,* Vol. 195, pp. 1076-1077, 1962.
17. Claus, G., and B. Nagy, "A Microbiological Examination of Carbonaceous Chondrites," *Nature,* Vol. 192, pp. 594-596, 1961.
18. Degens, E. T., and M. Bajor, "Amino Acids, Sugars, and Nucleic Acids in the Bruderheim and Murray Meteorite," *Geochimica et Cosmochimica Acta,* In press.

REFERENCES (Cont'd)

19. Lipman, C. B., "Are There Living Bacteria in Stony Meteorites?", *American Museum Novitates* No. 588, 19 pp., 1932.

20. Nagy, B., W. G. Meinschein, and D. J. Hennessy, "Mass Spectroscopic Analysis of the Orgueil Meteorite: Evidence for Biogenic Hydrocarbons," *Annals of the New Academy of Science,* Vol. 93, pp. 27-35, 1961.

21. Reynolds, O. E., "Space Biosciences," *AIBS Bulletin,* Vol. 12, pp. 48-51, 1962.

22. Jenny, H. "Derivation of State Factor Equations of Soils and Ecosystems," *Soil Science Society of America, Proceedings,* Vol. 25, pp. 385-388, 1961.

23. Thorman, H. C., *Review of Techniques for Measuring Rock and Soil Strength Properties at the Surface of the Moon,* TR 32-374, Jet Propulsion Laboratory, Pasadena, 1962.

24. Simonson, R. W., "What Soils Are," *U.S.D.A. Agricultural Yearbook,* Separate No. 2785, pp. 17-31, 1957.

25. Nikiforoff, C. C., "General Trends of the Desert Type of Soil Formation," *Soil Science,* Vol. 43, pp. 105-131, 1937.

26. Tikhov, G. A., "Is Life Possible on Other Planets?" *Journal of the British Astronomical Association,* Vol. 65, pp. 193-204, 1955.

27. Tikhov, G. A., "Astrobiology," *Principal Works of Astrobotany and Astrophysics,* 1912-1957, pp. 24-134, OTS: 60-11, p. 367, March 11, 1960.

28. Imshenetsky, A. A., Presentation given at Seminar on Soviet Space Science, UCLA, Los Angeles, May 8, 1962.

29. Imshenetsky, A. A., "General Microbiology in the U.S.A.," *Microbiology,* Vol. 30, pp. 605-613, 1962.

30. Shcherban, A., "Science Serves the People." *Impact of Science on Society,* Vol. 12, pp. 119-134, 1962.

31. Meisel, M. N., G. A. Medvedeva, and V. M. Alekseeva, "Discrimination of Living, Injured, and Dead Microorganisms," *Microbiology,* Vol. 30, pp. 699-704, 1962.

32. Novikov, P. M., "Constant-Electrode Device for the Study of the Dynamics of Oxidation-Reduction Conditions in Soils," *Pochvovedenie* 1960 (5), pp. 113-114, 1960.

33. Tyurin, I. V., "The Development of Soil Science in the USSR in Forty Years," *Pochvovedenie* 1957 (11), pp. 1-13, 1957.

34. Nikiforoff, C. C., "Reappraisal of the Soil," *Science,* Vol. 129, pp. 186-196, 1959.

35. Swan, L. W., "The Ecology of the High Himalayas," *Scientific American,* Vol. 205, pp. 67-78, 1961.

36. Killian, C., and D. Fehér, "Recherches Sur Les Phénomènes Microbiologiques des Sols Sahariens," *Encyl. Biol.,* Vol. 21, pp. 1-44, 1939.

37. Llano, G. A., "The Terrestrial Life on the Antarctic," *Scientific American,* Vol. 207, pp. 213-230, 1962.

REFERENCES (Cont'd)

38. Powell, J. W., *Report on the Lands of the Arid Region of the United States,* p. 15, The Belknap Press, Cambridge, 1962.

39. Abelson, P. H., "Extra-Terrestrial Life," *Proceedings of the National Academy of Sciences,* Vol. 47, pp. 575-581, 1961.

40. Biel, E. R., "Microclimate, Bioclimatology, and Notes on Comparative Dynamic Climatology," *American Scientist,* Vol. 49, pp. 326-357, 1961.

41. Cameron, R. E., "Soil Studies—Desert Microflora," Space Programs Summary *No. 37-15,* pp. 12-20, Jet Propulsion Laboratory, Pasadena, April 1 to June 1, 1962.

42. Buckingham, E., "Studies on the Movement of Soil Moisture," *U.S.D.A. Bureau of Soils, Bulletin* 38, 61 pp., 1907.

43. Shaw, M. D., and W. C. Arble, "Bibliography on Methods for Determining Soil Moisture," *Pennsylvania State University Engineering Research Bulletin B-78,* 1959.

44. Bower, C. A., "Determination of Sodium in Saline Solutions With a Glass Electrode," *Soil Science Society of America Proceedings,* Vol. 23, pp. 29-31, 1959.

45. Mortland, M. M., "Using a Glass Electrode for Estimating Exchangeable Potassium in Soils," *Quarterly Bulletin Michigan Agricultural Experiment Station,* Vol. 43, pp. 491-498, 1961.

46. Baas Becking, L. G. M., I. R. Kaplan, and D. Moore, "Limits on the Natural Environment in Terms of pH and Oxidation-Reduction Potentials," *Journal of Geology,* Vol. 68, pp. 243-284, 1960.

47. Gumenski, B. M., and N. S. Komarov, "Soil Drilling by Vibration," Ministry of Municipal Services of the RSFSR in Moscow, (Translation by Consultants Bureau Enterprises, Inc., 1961).

48. Durbin, R. D., "Techniques for the Observation and Isolation of Soil Microorganisms," *Bot. Rev.,* Vol. 27, pp. 522-560, 1961.

49. Vilenskii, D. G., *Pochvovedenie* (Soil Science), 3rd Ed. Uchpedgiz. Moscow, 1957. (English translation by Israel Program for Scientific Translations for the National Science Foundation and the U.S. Dept. of Commerce), Washington 25, D. C., p. 93, 1960.

50. Cameron, R. E., *Areas for Soil Studies,* Biology Group, Jet Propulsion Laboratory, Pasadena, (Unpublished manuscript), September 13, 1962.

51. Jaeger, E., *The North American Desert,* Stanford University Press, Stanford, p. 31, 1957.

52. Cook, S. F., and N. Pace, "White Mountain High Altitude Research Station," *Science,* Vol. 116, pp. 697-700, 1952.

53. Hamilton, A., "White Mountain—High and Dry Research," *Westways,* 54(4/1), pp. 1-9, 1962.

54. Crowther, E. M., "The Relationship of Climatic and Geological Factors to the Composition of Soil Clay and the Distribution of Soil Types," *Proceedings of the Royal Society of London,* Ser. B., Vol. 107, pp. 1-30, 1931.

REFERENCES (Cont'd)

55. Gehman, H. M., "Organic Matter in Limestones," *Geochemica et Cosmochimica Acta,* Vol. 26, pp. 885-897, 1962.

56. Cameron, R. E., "Terrestrial Algae of Southern Arizona," *American Journal of Botany,* In press.

57. Cameron, R. E., "Morphology of Representative Blue-Green Algae," *Annals of the New York Academy of Sciences,* In press.

ACKNOWLEDGEMENTS

This report is a contribution from the Bioscience Group of the Chemistry Section, Space Science Division, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California.

Presented as an invitational paper before the Synapsis Club, University of California, Riverside, California, December 3, 1962.

Assistance in sample collection and analysis was provided by Frank Morelli and Gerald Blank. Assistance on instruments and probes was supplied by Howard Britton. George Hobby critically reviewed the manuscript and gave valuable suggestions. The White Mountain Research Station provided facilities during the tenure of the study at high altitudes.